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REPORT NO. T5-92

THE USE OF TYMPANOMETRY TO DETECT AEROTITIS MEDIA IN HYPOBARIC CHAMBER OPERATIONS

U S ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

Natick, Massachusetts

April 1992

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UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE 31 January 1992

3. REPORT TYPE AND DATES COVERED Final

4. TITLE AND SUBTITLE
The Use of Tympanometry to Detect Aerotitis Media in Hypobaric Chamber Operations

5. FUNDING NUMBERS

6. AUTHOR(S)
V.A. Forte, Jr., J.A. Devine, P.B. Rock and A. Cymerman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Research Institute of Environmental Medicine, Natick, MA 01760-5007, and Natick Research, Development and Engineering Center, Natick MA 01760-5007

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Army Research and Development Command, Fort Detrick, MD 21701-5012

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Diagnosis and quantification of aerotitis media were performed using a modified commercially-available tympanometer under hypobaric conditions. Subjects were 22 males and 9 females, 22-43 years of age who were tested in each ear with the tympanometer prior to and after exposure, sequentially at the barometric pressure plateaus of 706, 656, 609, 586, 564, and 522 mm Hg, and following an induced ear block during a 1-min descent from 522 to 586 mm Hg. Each subject was examined once either alone or in pairs during a 90-min exposure. Aerotitis media was detected using tympanometry at simulated altitude as indicated by the difference between measurements made prior to and during induced ear blocks as well as following relief of the pressure differential with a Valsalva maneuver. There were no significant differences between pre-and post-hypobaria. Our study suggests that tympanometry can be a valuable tool in managing aerotitis media in the aeromedical environment.

14. SUBJECT TERMS
Aerotitis Media, Eustachion Tubes, Hypobaria

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

THE USE OF TYMPANOMETRY TO DETECT AEROTITIS MEDIA IN HYPOBARIC CHAMBER OPERATIONS

Vincent A. Forte, Jr.

James A. Devine

LTC Paul B. Rock

Allen Cymerman

Altitude Physiology and Medicine Division

Environmental Physiology and Medicine Directorate

U.S. Army Research Institute of Environmental Medicine

Kansas Street

Natick, MA. 01760-5007

January 1992

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SUMMARY

The ability of a tympanometer to diagnosis and quantify aerotitis media under hypobaric conditions was tested. Subjects were 22 males and 9 females, 22-43 years of age. Tympanometry was performed in each ear with the tympanometer prior to and after hypobaric exposure, and sequentially at the barometric pressure plateaus of 706, 656, 609, 586, 564, and 522 mm Hg. Additionally, each ear was evaluated with the tympanometer following an induced ear block during a 1-min descent from 522 to 586 mm Hg. Aerotitis media was detected using tympanometry at simulated altitude as indicated by the difference between measurements made during induced ear blocks and those made prior to inducement, as well as following relief of the pressure differential using the Valsalva maneuver. There were no significant differences in tympanometric measurements between pre- and post-hypobaria. Our study suggests that tympanometry can be a valuable tool in managing aerotitis media in the aeromedical environment.

INTRODUCTION

Aerotitis media (barotrauma, ear block) is the most prevalent medical problem occurring within hypobaric chamber (Crowell, 1983) and aviation operations (Demar et al., 1981). The condition, which may occur in one or both ears, results from the inability to equilibrate pressure within the middle ear cavity with the ambient pressure following an increase in ambient air pressure (Dickson et al., 1944). The resulting pressure differential between the middle ear and the atmosphere stretches the tympanic membrane producing discomfort or pain. The relative negative middle ear pressure can cause a narrowing or collapse of the Eustachian tube, promoting a self-perpetuating pathological process (Bluestone et al., 1972) which may be further aggravated by transudation of fluid into the middle ear cavity (Brookler, 1975).

In healthy individuals, pressure in the middle ear can be equalized with ambient atmospheric pressure by swallowing, yawning, or tighting the muscles of the throat. These procedures cause contraction of pharyngeal muscles and open the orifices of the Eustachian tubes, allowing ventilation of the middle ear. Another, and perhaps more effective, means of ventilating the middle ear, and one which is frequently used in hypobaric chambers and the aviation environment, is the Valsalva maneuver. This maneuver forces air into the Eustachian tubes to raise

middle ear pressures to equal or exceed the ambient air pressure.

If existing pressure differentials are sufficient to collapse the Eustachian tubes, middle ear ventilation may not be possible by any of the previously mentioned methods. In this situation, the pressure differentials may be reduced or eliminated by returning to a lower ambient pressure (i.e., higher altitude). Once the pressure differential is reduced, techniques to ventilate the middle ear may again be attempted.

Difficulty equalizing pressure between the middle ear and ambient air may be increased when the Eustachian tubes or their openings are swollen due to inflammation or infection. In these instances, the use of short-acting antihistamines or decongestants can be helpful to reduce swelling. To lessen the risk of aerotitis media in the aeromedical environment, it is normal practice to restrict the hypobaric exposure to those individuals who can not ventilate their middle ears.

Although the techniques listed above for relieving aerotitis media can be effective, it is often difficult to fully evaluate their success because there has been no convenient, objective means of consistently detecting the presence or absence of aerotitis media. Traditionally, aerotitis media has been detected by the presence of subjective symptoms (i.e., pain) and/or by direct otoscopic visualization. Both methods have inadequacies. Subjective symptoms are prone to individual variation in perception, tolerance, and reporting of pain.

Direct assessment of middle ear function requires

observation with an otoscope to document tympanic membrane movement in response to either a Valsalva maneuver or transient pressure changes introduced into the external ear canal with a pneumatic challenge. However, because observation of tympanic membrane movement is also a subjective finding, experienced examiners may be uncertain or disagree on both the actual findings and the interpretations of those findings (Cante et al.; Paradise et al., 1980). Ingelstedt et al., (1967), developed a micro flow system for indirectly measuring middle ear pressure changes; a system which is capable of detecting aerotitis media during hypobaric conditions. However, the micro flow system is cumbersome, and requires technically skilled personnel to operate. Groth et al., 1981, found that the quantitative impedance method was comparable to the micro flow method.

The tympanometer is an impedance device designed to detect congestive pathology in the middle ear without the use of an otoscope. A number of studies have suggested that tympanometry may provide a method to evaluate middle ear ventilation that requires less experience and subjective interpretation on the part of the examiner than previous methods (Beery et al., 1975; Brooks, 1968; Paradise et al., 1976; Shurin et al., 1977). It has been used successfully in routine clinical screening of pediatric populations for middle ear defects and to detect and follow the results of middle ear effusions (Cante et al., 1980; Jerger, 1970; Paradise et al., 1980; Paradise et al., 1976). Tympanometry has also been used for detecting middle ear

pathology prior to flight and for a study of susceptibility to aerotitis media (Demar et al., 1981; Tian, 1988). To date, however, no studies have been reported which specifically examine the ability of tympanometry to detect aerotitis media while it is present in an actual hypobaric environment. We performed tympanometric measurements on 31 test subjects after inducing aerotitis media following a rapid increase of atmospheric pressure (522 mm Hg to 586 mm Hg) in a hypobaric chamber and compared the results with measurements previously made at 586 mm Hg without the ear block. Additionally, serial measurements were made during ascent to characterize the tympanometer operation at altitude. Pre- and post-hypobaric exposure measurements were made to detect possible residual effects of aerotitis media.

METHODS

All tympanometric measurements in this study were made with a modified Grason-Stadler GSI-27 tympanometer. Modifications were necessary because the instrument was designed for use at barometric pressures greater than 630 mm Hg. To allow use at atmospheric pressures as low as 522 mm Hg, the Grason-Stadler Company reduced the internal volume of the instrument's air reservoir (modification no. GS1727-2010A) and probe syringe (modification no. GS1727-0410A). With these changes, the instrument was able to achieve its pressure sweep more rapidly and thus compensate for ambient pressures less than 630 mm Hg.

Two fixed test cavities (0.5 and 2.0 ml) provided by the Grason-Stadler Company were used to validate instrument calibration from 760 to 522 mm Hg.

Adult volunteers (22 males and 9 females) served as test subjects after giving their informed consent. Subjects ranged in age from 22 to 43 years. Each was screened with a medical history and a Flying Duty Medical Exam prior to inclusion into the study. Potential subjects with any otorhinolaryngology pathology or after medical contraindication to altitude exposure were excluded from participation.

Test subjects were exposed to hypobaric conditions up to a simulated altitude of 3028 m (10,000 ft; 522 mm Hg) in the USARIEM Hypobaric Chamber in Natick, MA. Each subject underwent one exposure lasting approximately 90 min. The flight profile is presented in Figure 1. 522 mm Hg was chosen as the lowest pressure for data collection in this study because we have observed in 20 years of hypobaric chamber operations that 90% of spontaneous cases of aerotitis media occurred between 522 mm Hg and sea-level pressure. Subjects were exposed singularly or in pairs, and none received supplemental oxygen during the exposure. Both ears were tested consecutively in every subject.

Each subject received 11 tympanometer examinations: at sea level prior to entering the hypobaric chamber, during ascent stopping at 706, 656, 609, 586, 564, 522 mm Hg and following descent to 586 mm Hg. After reaching 522 mm Hg during descent, subjects were asked to refrain from ventilating their middle ears

during a 1-minute descent to 586 mm Hg. This induced mild symptoms of aerotitis media (fullness or some discomfort) in at least one ear of all the subjects. After tympanometric measurements were made during the induced aerotitis media, each subject performed a Valsalva maneuver to relieve the ear block and to provide measurements of ventilated middle ears for comparison to measurements made at 586 mm Hg on ascent. Then, to determine if the tympanometer could be used to differentiate between aerotitis media and an over-inflated middle ear, the subject held a forced Valsalva maneuver while measurements were taken again. A final tympanogram was performed following return to sea-level pressure to detect any residual aerotitis media and to determine if post-exposure values recovered to pre-exposure values.

Because body position has been shown to affect Eustachian tube function (Groth et al., 1980), all tests were accomplished with the subject seated in the upright position. All measurements were performed by one investigator to minimize potential discrepancies in technique, although other studies (Beery et al., 1975; Brooks, 1968; Paradise et al., 1976; Shurin et al., 1977) suggest there is very little difference in measurements by different operators using standard procedures.

The tympanometric measurements used to determine middle ear conditions were: 1) ear canal volume, which represents the space between the probe tip and tympanic membrane; 2) tympanic volume (Tymp Peak), which represents volumetric displacement of the

tympanic membrane; and 3) tympanic pressure (Tymp Pressure) measured in decaPascals (daPa, 1.0 daPa = 0.039 in. H_2O). Tymp pressure represents the amount of pressure used to displace the tympanic membrane. A brief explanation of the operating principles of the tympanometer is found in the addendum.

The data were analyzed using the Biomedical Computer Programs (BMDP) library program (Dixon et al., 1979). A three-way (subject x level of hypobaria x test condition) analysis of variance (ANOVA) was used to compare tympanic membrane measurements before, during, and after voluntarily-induced aerotitis media. If significant effects or interactions between factors were found, Tukey's critical difference was calculated and used to localize significant differences between conditions. The level of significance for all statistical analyses was $p<0.05$.

RESULTS

Three patterns of tympanograms were identified that fit Jerger's Type A, B and C classifications of middle ear status (Jerger, 1970). The Type A pattern reflects a normal middle ear response with maximum compliance of the tympanic membrane at or near ambient air pressure (Fig. 2). Type B pattern is a flat, non-responsive contour usually associated with middle ear fluid, thickened drum, or impacted cerumen. With this pattern the tympanometer registers no tymp volume peak (NP), no tymp pressure

(NP), and no reflex response (NR) or tone (NT) as illustrated in Fig. 2. The type B pattern is interpreted to represent a "full ear block." Type C pattern is characterized by maximum compliance at a large negative pressure and is associated with a retracted tympanic membrane. This pattern is interpreted as a "partial ear block" (Fig. 2, i.e., -410 daPa) where the pressure differential between the middle ear and ambient environment distended the tympanic membrane but did not entirely eliminate its function.

Of the 62 measurements made during induced aerotitis media, 44 (70%) were Type B patterns and designated "full ear blocks" while 14 (23%) were Type C pattern or "partial ear blocks." In four different subjects, the conditions failed to induce aerotitis media in one of their ears, and the pattern in that ear remained Type A. Resolution of the full or partial ear block was accomplished with the Valsalva maneuver in all subjects.

Subsequent tympanometer examinations during forced (held) Valsalva maneuvers found 57 (92%) patterns consistent with a full ear block (type B pattern). A partial ear block (type C pattern) was observed in one ear of one subject. Also, in one ear of four different subjects (all unrelated to the four subjects in whom an ear block could not be induced in one of their ears) the Valsalva maneuver could not be sustained. The only definitive difference between aerotitis media and forced Valsalva maneuver that could be identified was that the mean ear canal volume during forced Valsalva (1.98 ± 12 ml) was significantly lower than during

aerotitis media (2.13 ± 10 ml).

The effect of decreasing barometric pressure on tympanometrically measured ear canal volumes was indicated as larger values in subjects with adequately ventilated ears (Table 1). The mean measured volumes were progressively larger than the values calculated. This comparison was made using Boyle's Gas Law and the group mean ear canal volume of 1.41 ml measured at sea level (Figure 3). There were no significant differences observed between pre- and post-induced aerotitis media values at 586 mm Hg, or between values pre- and post-hypobaric exposure at the same pressure following a brief sojourn to 522 mm hg. (Table II).

DISCUSSION

Results of this study suggest that a modified, commercially available tympanometer can be used to detect and follow aerotitis media during hypobaric operations. Detection is based on alteration in the tympanogram pattern consistent with partial or complete disruption of middle ear function. Retraction of the tympanic membrane due to failure to ventilate the middle ear during descent results in a progressive decrease in compliance due to a negative pressure differential between ambient air and the middle ear cavity. Eventually, the pressure differential becomes sufficient to immobilize the tympanic membrane producing a flat curve. The negative shift of the tympanometer curve

caused by negative middle ear pressure has been documented in previous studies. The characteristic shape of the curve is used clinically to detect middle ear disease (Brooks, 1968; Fria et al., 1980; Jerger, 1970; Roeser et al., 1977; Shurin et al., 1977). Our results suggest a similar mechanism through which a flat curve is produced by a rigid tympanic membrane caused by the pressure differential with ambient pressure.

Importantly, the resolution of the aerotitis media was able to be detected by the return to baseline values following the Valsalva maneuver. Further, tympanometry readily distinguished between negative pressure of an ear block and a greatly overinflated middle ear produced by a Valsalva maneuver on the basis of decreased ear canal volume in the overinflated ear. It remains problematic whether tympanometry could distinguish a partial overpressure from a "partial ear block." This is of practical importance since some of the residual discomfort in patients following attempts to relieve aerotitis media may be from residual overpressure rather than from negative pressure in the middle ear.

The practical significance of our findings is that tympanometry offers an objective means of detecting aerotitis media and its resolution, making it a useful adjunct to management of that condition in the operational aeromedical environment. To date, detection of an ear block in the operational environment has relied heavily on otoscopy which requires a skilled examiner. Results from otoscopic examinations

are subjective and even experienced examiners may be uncertain or interpret the same findings differently. Use of the tympanometer, on the other hand, requires less skill and gives little margin for subjective errors. The only caveat to the usefulness of the tympanometer is that it requires modification to perform adequately at operational altitudes. Once the initial modification was made to our tympanometer, the instrument functioned satisfactorily at altitude.

Serial measurements of ear canal volumes made during ascent were performed to discern if data collected from the tympanometer could provide a reproducible marker of the ambient pressure at different altitudes. The results of the present study suggest that they could.

Since the tympanometer interprets the less dense pressure as an increased ear canal volume, it was thought that the pressure/volume change would correlate closely with Boyle's Law. Yet, as shown in Figure 3, that was not the case. The intercepts of the calculated and measured value lines are similar, but the slopes are very different. This discrepancy is thought to be related to the two reservoirs of air within the instrument, where a lower pressure in the fixed cell cavities lead to larger than actual ear canal volume calculations. Nevertheless, the tympanometer data appear to be reproducible. Because of these findings, it is believed that the use of a tympanometer may prove to be helpful in managing aerotitis media. Additionally, the data suggests that the tympanometer could be used to determine

the pressure/altitude of onset and resolution of an ear block.

The tympanometer may also be useful in other roles in the aeromedical environment as "pre-flight" screening for transient pathologic conditions of the middle ear such as upper respiratory infections and allergies which have been implicated as major causes of aerotitis media (Demar et al., 1981; Tian, 1988). Also, tympanometry may be useful for disclosing "post-flight" residual pathological conditions.

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ADDENDUM

During tympanometer measurements, a low pitch tone (226 Hz) is presented to the tympanic membrane via a hand-held probe positioned against the entrance of the external ear canal. The probe tone is used to measure compliance changes within the middle ear system while air pressure within the ear canal is varied from a +200 decaPascals (daPa, 1,0 daPa = 0.039 in H_2O) to -400 daPa. In the absence of middle ear pathology, the middle ear system stiffens and becomes less mobile with either a greater positive or negative pressure while the most compliance occurs when the pressure within the ear canal is brought back to atmospheric pressure (i.e., 0 daPa). Therefore, by varying the pressure within the ear canal, it is possible to make a series of compliance measurements for evaluating tympanic membrane, middle ear status, and Eustachian tube performance. The tympanic membrane compliance was plotted against the changes in pressure, creating a tympanogram. A final acoustic reflex test uses a loud sound (85-105 dB) at the same air pressure value of the compliance peak. The acoustic reflex stimulus serves to validate tympanometric results since an acoustic reflex can not be measured in the absence of a compliance peak.

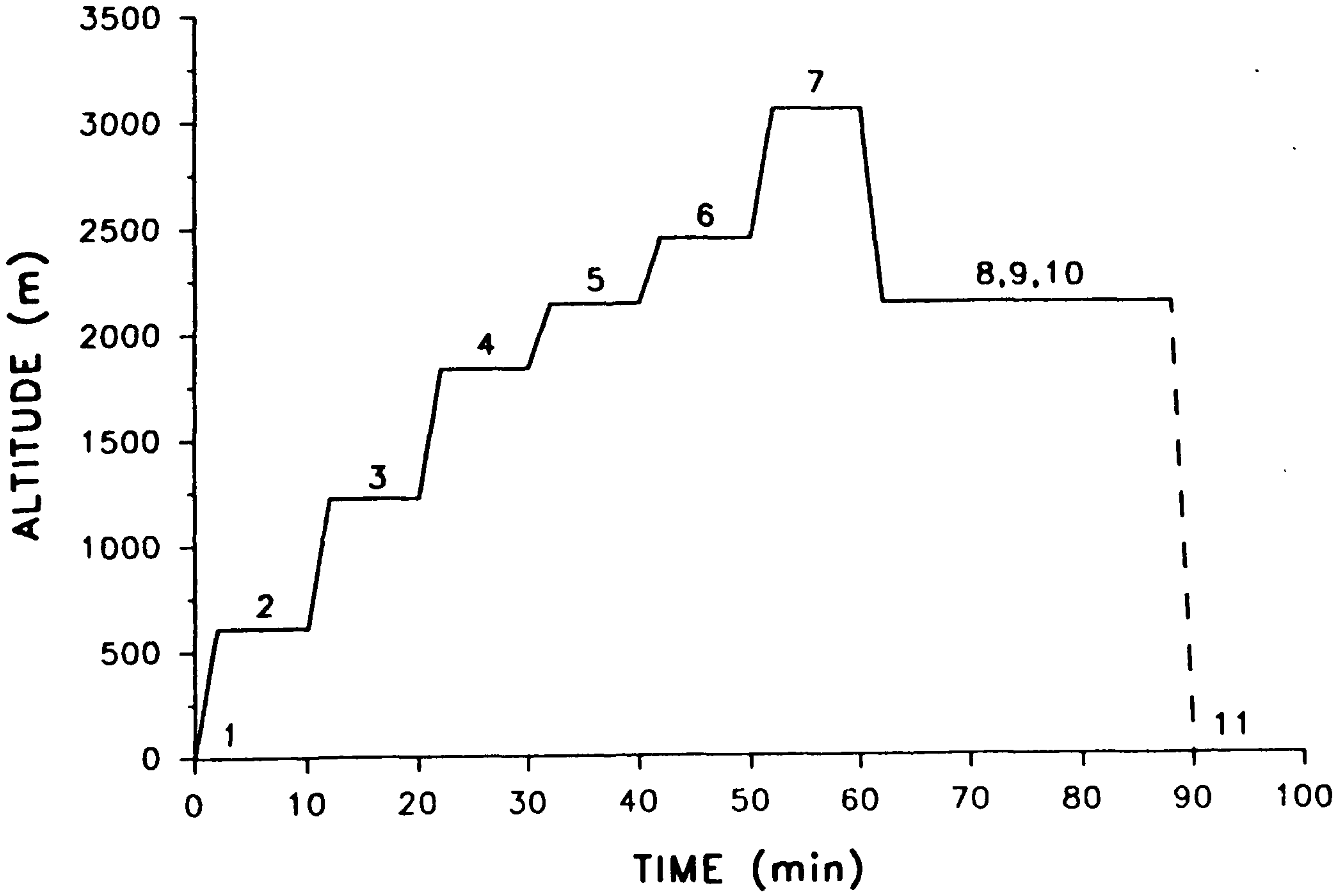
FIGURE LEGENDS

Figure 1. Flight profile showing the barometric pressure/altitude plateaus where 11 tympanometer examinations were performed on each subject during a 90-min exposure.

Figure 2. Tympanogram data and plots showing examples of: normal middle ear status on the left, a flat non-responsive contour described as a "full ear block" in the center, and a large negative pressure resulting in retracted tympanic membrane and explained as a "partial ear block" on the right.

Figure 3. Each tympanometer point represents the mean of 62 values ($\pm$ S.E.M.). The regression equations for the tympanometer data and Boyle's law are $y = 0.14X + 1.37$, $r = 0.997$ and $y = 0.64X + 1.40$, $r = 0.997$, respectively.

FIGURE 1



TEST #	ALT (FT)	(TORR)
1	0	760
2	2,000	706
3	4,000	656
4	6,000	609
5	7,000	586
6	8,000	564
7	10,000	522
8	7,000	586
9	7,000	586
10	7,000	586
11	0	760

FIGURE 2

EAR CANAL	ml	1.2
	ml	0.5
TYMP PEAK	daPa	-10
REFLEX	dB HL	85

EAR CANAL	ml	1.2
	ml	NP
TYMP PEAK	daPa	NP
REFLEX	dB HL	NR

EAR CANAL	ml	1.4
	ml	0.1
TYMP PEAK	daPa	-410
REFLEX	dB HL	NT

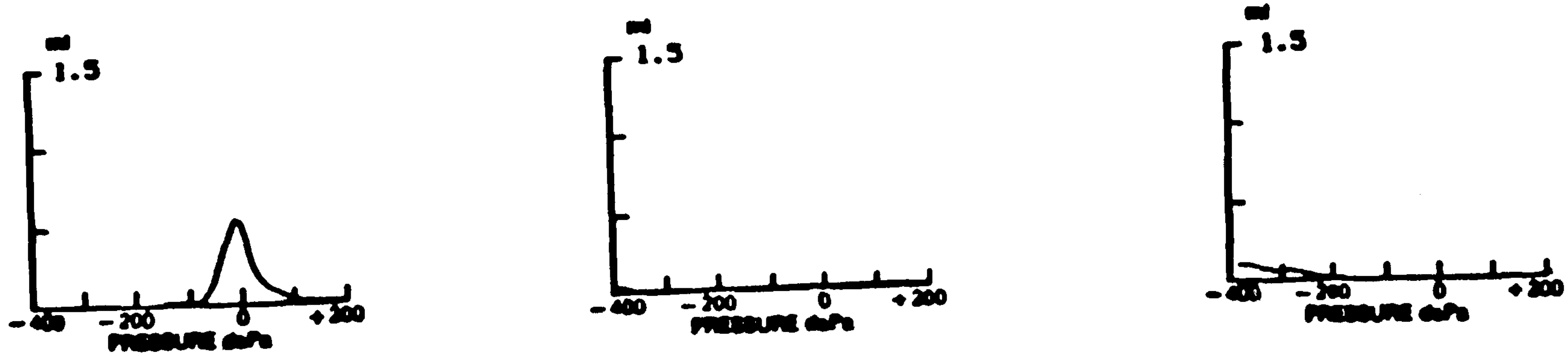
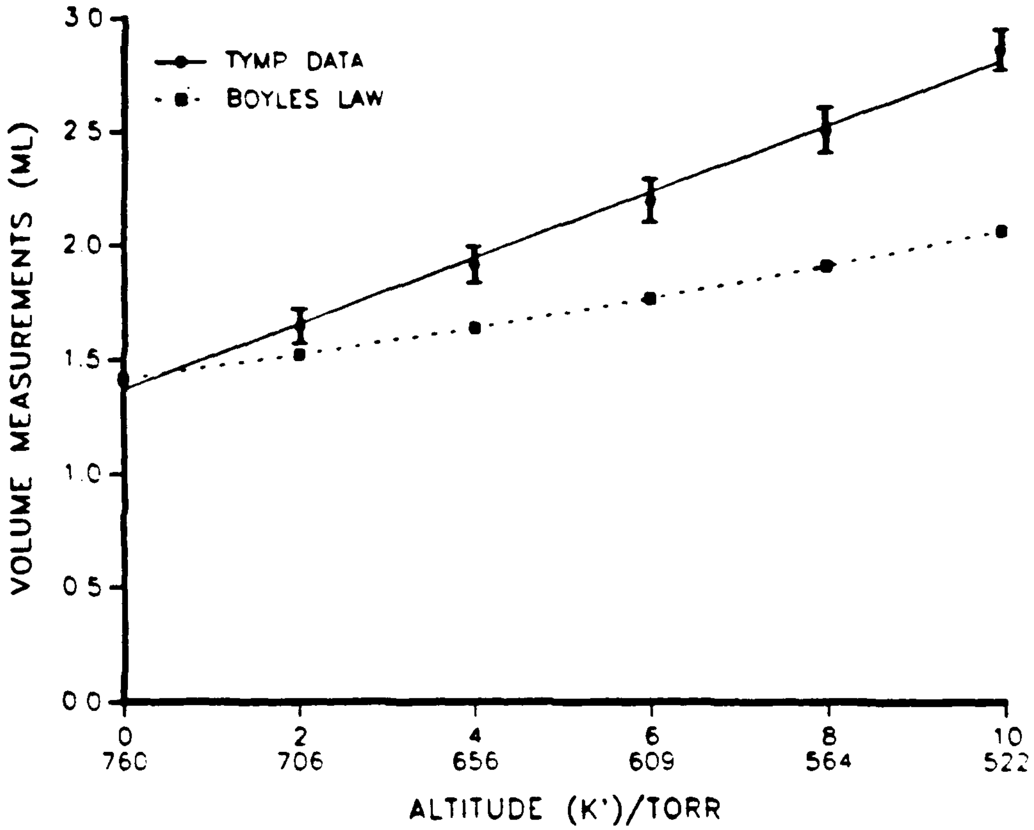


FIGURE 3



TYMP DATA
BOYLES LAW
VOLUME MEASUREMENTS (ML)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
760
2
706
4
656
6
609
8
564
10
522
ALTITUDE (K')/TORR

TABLE 1

EFFECT OF DECREASING BAROMETRIC PRESSURE ON EAR CANAL VOLUMES

	TORR					
	760	706	656	609	564	522
TYMPANOMETER	1.41 ± 0.07	1.65 ± 0.08	1.92 ± 0.08	2.20 ± 0.09	2.50 ± 0.10	2.86 ± 0.09
BOYLES LAW	1.41	1.52	1.64	1.77	1.91	2.10

Values for **TYMPANOMETER** are means ± S.E.M., ml, n=62.
Values for **BOYLES LAW** are calculated on 1.41 ml at 760 Torr.

TABLE 2

COMPARISON OF TYMPANOMETER MEASUREMENTS BETWEEN PRE AND POST AEROTITIS MEDIA AND HYPOBARIC EXPOSURE

	Aerotitus Media		**Hypobaric Exposure**	
	Pre	Post	Pre	Post
Ear Canal Volume	2.33 ± 0.09	2.32 ± 0.09	1.43 ± 0.08	1.43 ± 0.05
Tymp. Volume	0.96 ± 0.08	0.98 ± 0.06	0.75 ± 0.06	0.82 ± 0.05
Tymp. Pressure	-8.20 ± 2.50	-14.3 ± 4.50	-22.3 ± 2.40	-23.9 ± 3.90

Values are Mean ± S.E.M., ml, N=62.
Tympanic membrane displacement volume (tymp. volume).
Tympanic pressure in decaPascals (daPa).
There were no significant differences between pre and post measurements in all comparisons.

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